

# NSV 11749, AN ELDER SIBLING OF THE BORN AGAIN STARS V605 AQL AND V4334 SGR?

M. M. MILLER BERTOLAMI<sup>1,2</sup>, R. D. ROHRMANN<sup>3</sup>, A. GRANADA<sup>4</sup> & L. G. ALTHAUS<sup>1,2</sup>

<sup>1</sup>Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque s/n, 1900 La Plata, Argentina.

<sup>2</sup>CCT-La Plata, CONICET, Argentina.

<sup>3</sup>Instituto de Ciencias Astronómicas, de la Tierra y del Espacio, CONICET, Av. de España 1512 (Sur) CC 49,5400 San Juan, Argentina.

<sup>4</sup>Observatoire Astronomique de l'Université de Genève 51, Chemin des Maillettes, CH-1290, Sauverny, Suisse.

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## ABSTRACT

We argue that NSV 11749, an eruption observed in the early twentieth century, was a rare event known as “very late thermal pulse” (VLTP). To support our argument we compare the lightcurve of NSV 11749 with those of the two bonafide VLTP objects known to date, V4334 Sgr and V605 Aql, and with those predicted by state of the art stellar evolution models. Next, we explore the IPHAS and 2MASS catalogues for possible counterparts of the eruption. Our analysis shows that the VLTP scenario outperforms all other proposed scenarios as an explanation of NSV 11749. We identify an IPHAS/2MASS source at the eruption location of NSV 11749. The derived colors suggest that the object is not enshrouded in a thick dust shell as V605 Aql and V4334 Sgr. Also the absence of an apparent planetary nebula (PN) at the eruption location suggests differences with known VLTP objects which might be linked to the intensity of the eruption and the mass of the object. Further exploration of this source and scenario seems desirable. If NSV 11749 was a born again star, it would be the third event of its kind to have been observed and will strongly help us to increase our understanding on the later stages of stellar evolution and violent reactive convective burning.

*Subject headings:* stars: AGB and post-AGB — novae, cataclysmic variables — stars: individual (NSV 11749, V4334 Sgr, V605 Aql)

## 1. INTRODUCTION

About a fifth of the stars departing from the Asymptotic Giant Branch (AGB) are expected to undergo a final thermal pulse during their post-AGB evolution (Iben 1984). When this happens, the pre-white dwarf is predicted to be temporarily reborn as a yellow giant (Schoenberner 1979) in the so called “Born Again AGB” scenario (Iben 1984). The transition from the pre-white dwarf to the giant configuration is expected to be very rapid; being of a few years in the very late thermal pulse (VLTP) flavor (Iben & MacDonald 1995) and of the order of a century in the late thermal pulse (LTP) case (Schoenberner 1979). Due to the short duration of these events, although 10% of post-AGB stars are expected to undergo a VLTP, they are extremely rare from an observational perspective. Indeed, only two objects (V605 Aql and V4334 Sgr) have been identified as stars undergoing a VLTP (see Duerbeck et al. 2000, 2002), while a third has been identified with the LTP flavor of the scenario (FG Sge, see Jeffery & Schönberner 2006 and references therein). Although observationally rare, individual VLTP stars are extremely valuable as they are key to understand the formation of C-rich H-deficient stars, such as [WC]-CSPNe, PG1159 and RCrB (see Werner & Herwig 2006 and Clayton 1996 for a review) and the formation of H-deficient white dwarfs—which comprise about  $\sim 20\%$  of known white dwarfs. In addition, born again star events are a key test for our understanding of s-process during the thermal pulse phase of the AGB (Asplund et al. 1999 and Jeffery & Schönberner 2006) and also for understanding of reactive convective burning in the interior of stars

(Herwig et al. 2011).

A rough estimate suggests that the birth rate of planetary nebulae in our galaxy is of about  $\sim 1$  every year (Zijlstra 2002). If 10% of their central stars become VLTP giants, then we should expect such events in our galaxy to take place at a rate of about one per decade. Due to their high intrinsic brightnesses ( $M_v \sim -2... -4$ ) these objects can be easily detected at large distances within our galaxy. Hence, it should not be strange if some born again eruptions are waiting to be identified in old and new star surveys. This could be the case for the object NSV 11749. After an excellent systematic study of all useful Harvard plates, Williams (2005) was able to reconstruct the outburst lightcurve of this star. The plates show that the object was fainter than  $m_{pg} \sim 15.5$  on 1897.6, became visible for the first time at  $m_{pg} \sim 14$  on 1899.5 and reached maximum at  $m_{pg} \sim 12.5$  on 1903.4. Then it remained at about maximum brightness until 1907.6 when it started to decline, becoming undetectable after 1911.6—with four possible detections at  $m_{pg} \sim 17$  some decades later. Finally, during the declining phase, the star showed three sudden disappearances (fainter than  $m_{pg} \sim 14$ ) before finally fading into oblivion. In this letter we argue that NSV 11749 was a VLTP event and explore for possible counterparts in IPHAS and 2MASS catalogs.

## 2. THE LIGHTCURVE OF NSV 11749

The lightcurve of NSV 11749 bears a strong resemblance with those of VLTP-objects (V4334 Sgr and V605 Aql). As can be seen in Fig. 1 NSV 11749 increased its brightness by more than 2.5 magnitudes in the first 2000 days of its eruption (i.e.  $dm_{pg}/dt > 0.45^m/\text{yr}$ ), stayed at a maximum brightness of  $m_{pg} \sim 12.6^m$  for about 1000

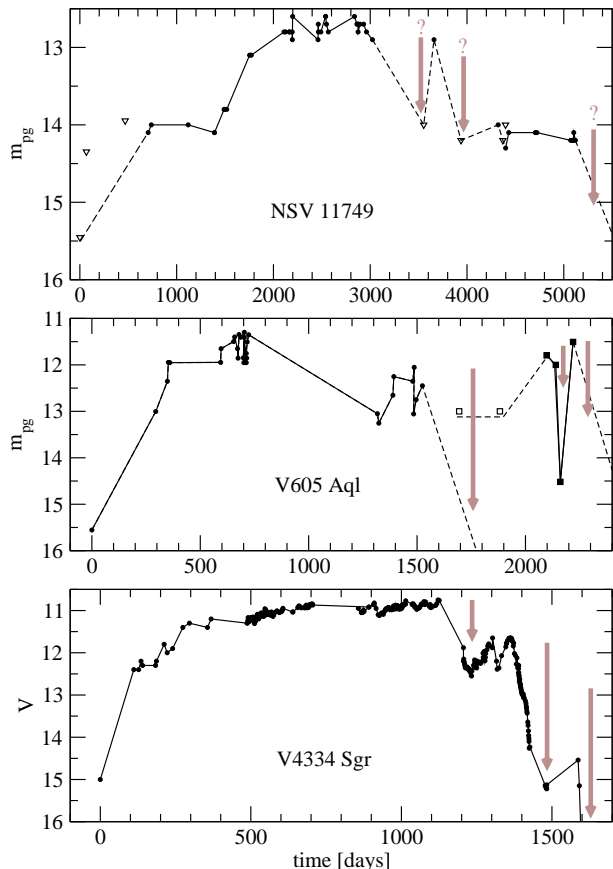


FIG. 1.— Lightcurves of NSV 11749, V605 Aql and V4334 Sgr. Thick downwards arrows indicate RCrB-like sudden drops in brightness.

days and then started to experience sudden dimmings (of more than  $1^m$ ) after finally disappearing from view  $\sim 13$  yr after its eruption. These three sudden disappearances of the star are particularly worth noting as they are very similar to those observed in the born again stars (Duerbeck et al. 2000, 2002). At least in the best studied born again star (V4334 Sgr, Duerbeck et al. 2000) it is clear that these sudden dimmings are caused by carbon-dust ejection episodes similar to those observed in R Coronae Borealis Stars (RCrB stars). In Fig. 1 we compare the lightcurve of NSV 11749 with those of the two known fast born again stars (V4334 Sgr and V605 Aql). The three lightcurves share the same main features: Namely, in a period of years they show an outburst stage, a steady stage at maximum brightness, a phase of RCrB-like declines and finally a complete disappearance from view. These similarities alone are a strong argument in favor of a similar explanation for all three stars, and thus for a born again (VLTP) explanation of the lightcurve of NSV 11749. However, quantitatively, there is a significant difference in the timescales of NSV 11749 and both V4334 Sgr or V605 Aql. In both V4334 Sgr and V605 Aql the sequence of events happened at a faster pace, increasing more than  $3.5^m$  during the first year. Also V4334 Sgr (V605 Aql) disappeared from view much faster, only  $\sim 4.4$  yr ( $\sim 6.3$  yr) after the eruption.

Then, the main question is to know if some born again stars could evolve a few times slower than observed in

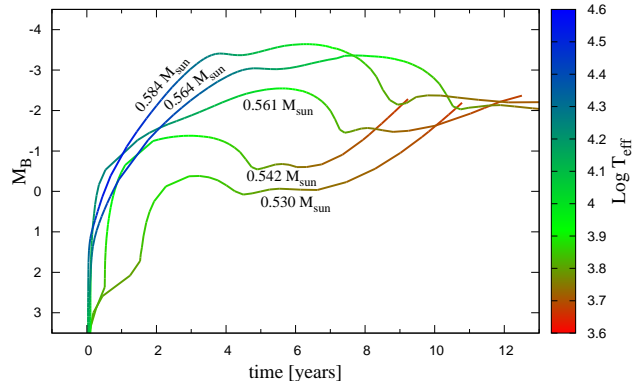


FIG. 2.— Theoretical  $M_B$  lightcurves for the fast-VLTP sequences of Miller Bertolami & Althaus (2007).

V4334 Sgr or V605 Aql. Stellar evolution models (Herwig 2001, Miller Bertolami & Althaus 2007) suggest that, indeed, that is the case.

### 3. THEORETICAL VLTP LIGHTCURVES

According to stellar evolution models VLTP eruption lightcurves and temperatures are dependent on the mass of the erupting star. Then, a direct comparison of NSV 11749 lightcurve with those of the two known VLTP objects (V605 Aql and V4334 Sgr) might be misleading.

In order to compare theoretical eruptions in VLTP models with the observed lightcurve of NSV 11749 it is necessary to construct theoretical  $B$  and  $V$  lightcurves. In the absence of bolometric corrections for H-deficient stars in the wide range of temperatures covered by VLTP eruptions, we have relied on theoretical model atmospheres to predict the expected  $B$  and  $V$  magnitudes of the stellar evolution models. Stellar atmospheres have been computed within the assumption of plane parallel geometry and LTE, including the opacities of all relevant major atoms (although without molecules or dust). Although plane parallel geometry is not justified at the very low surface gravities attained by the models some years after the eruption, it is reasonable during the first years of the eruption, i.e. before the development of the RCrB-stage in real stars. Abundances in stellar atmosphere computations have been chosen to reflect those predicted by VLTP models (Miller Bertolami & Althaus 2007), but tests show that lightcurves would be very similar if we had chosen abundances like those observed in V4334 Sgr (Asplund et al. 1999). Lightcurves computed with these model atmospheres and the stellar evolution sequences of Miller Bertolami & Althaus (2007) are shown in Fig. 2. Also shown is the effective temperatures predicted by the models during the eruption.

As shown in Fig. 2, our models predict different lightcurves depending on the mass of the remnant that undergoes the eruption. In particular note that after the fast initial rise, the lightcurves either stall or slightly diminish. After reaching a plateau for a few years, the theoretical lightcurves start to rise again as the sequences increase their luminosities without a strong change in temperature. However, this happens after the temperature falls below  $\text{log } T_{\text{eff}} \sim 3.7$  and then we expect RCrB-like events to develop. In fact, the three identified born again stars (FG Sgr, V605 Aql and V4334 Sgr) have

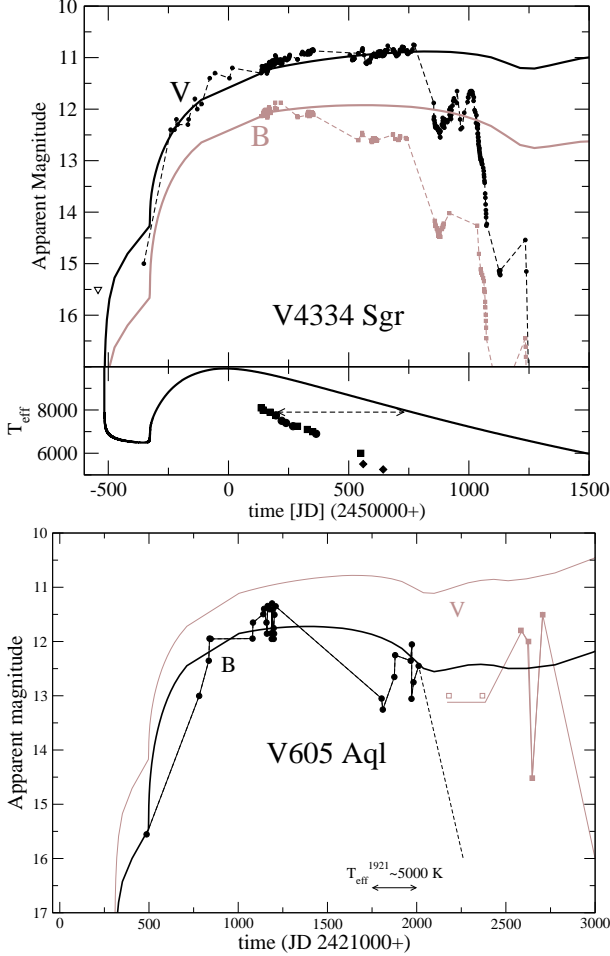


FIG. 3.— V and B lightcurves of V4334 Sgr (upper panel) and V605 Aql (lower panel) compared with our most similar lightcurve (sequence  $0.542M_{\odot}$  of Miller Bertolami & Althaus 2007).

shown RCrb extinction episodes after the temperature fell below  $\log T_{\text{eff}} \sim 3.7$  (Jeffery & Schönberner 2006, Clayton & De Marco 1997 and Duerbeck et al. 2000). Thus, synthetic lightcurves will not reflect the observed behavior from this point onwards. Then, the intrinsic maximum brightness of fast-VLTP sequences, after the fast rise in brightness, spans a wide range from  $\sim -1$  to  $-4$  both in V and B bands.

### 3.1. Test: Comparison with V605 Aql and V4334 Sgr

In order to understand to which extent our lightcurves can be trusted when comparing with real stars, we now compare our lightcurves with those of the two bonafide VLTP objects, V605 Aql and V4334 Sgr. In Fig. 3 we compare the lightcurve of our best fit model lightcurve ( $0.542M_{\odot}$ ) with the visual lightcurve of V4334 Sgr (Takamizawa 1997, Duerbeck et al. 1997, 2000) and with the photographic lightcurve of V605 Aql published by Duerbeck et al. (2002). To compare B and  $m_{\text{pg}}$  magnitudes, we adopt  $m_{\text{pg}} = B + 0.11$  as in Clayton & De Marco (1997). The similarities between the predicted and observed lightcurves are apparent. It is worth noting that no tuning of the theoretical models has been carried out in order to fit the observed lightcurves. Fig. 3 just displays our sequence with the most similar

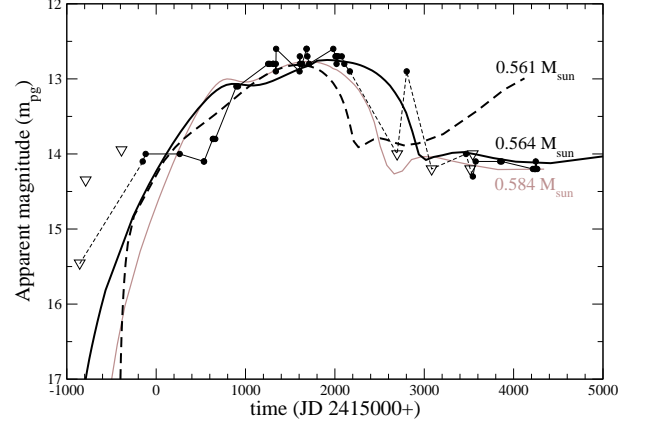


FIG. 4.— Lightcurve of NSV 11749 compared with some theoretical B lightcurves.

aspect with the observed ones.

Assuming the interstellar extinction model of Hakkila et al. (1997), we find for V4334 Sgr ( $V - M_V \sim 12.7^m$ , for our most similar lightcurve) a distance of  $d \sim 1.6$  kpc and  $A_V \sim 1.9^m$ . Interestingly enough, this value is within the recommended values by Kimeswenger (2002),  $d = 2^{+1}_{-0.6}$  kpc, on the basis of several independent distance determinations. Thus our  $0.542M_{\odot}$  lightcurve not only predicts a correct lightcurve shape for V4334 Sgr but also a correct absolute magnitude. Also, at the distance of  $d \sim 1.6$  kpc, and a derived value of  $A_B \sim 2.5^m$  our model also predicts the maximum brightness in the B band (see Fig. 3). On the other hand, it is clear from Fig. 3 that our model is not able to predict simultaneously the correct luminosity and temperature evolution (although its cooling speed,  $dT_{\text{eff}}/dt$ , is very similar to that of V4334 Sgr). Also the  $0.542M_{\odot}$  pre-outburst location in the HR diagram might be at variance with a possible pre-discovery detection of V4334 Sgr's progenitor in 1976 (see Miller Bertolami & Althaus 2007).

For the case of V605 Aql ( $B - M_B \sim 13.1^m$ , for our most similar lightcurve) we obtain a distance of  $d \sim 1.9$  kpc (and  $A_B \sim 2^m$ , assuming  $R = A_V/(A_B - A_V) = 3.1$ ), a value significantly lower than derived in previous works;  $2.7 \text{ kpc} < d < 6.0 \text{ kpc}$  (Clayton & De Marco 1997). However, it has to be kept in mind that larger distances would have been obtained if the extinction is not as high as suggested by Hakkila et al. (1997) in that particular direction of the sky ( $30^\circ < \lambda < 40^\circ$ ).

From these comparisons we conclude that our theoretical lightcurve shapes are very similar to those observed in real born again stars and can be used to identify born again star candidates. We notice, however, that theoretical models are not able to fit, simultaneously, all observed features. This is most probably due to the uncertainties in the treatment of the violent reactive convective burning of H in the models, something that it is still badly understood (Herwig et al. 2011).

### 3.2. Comparison with NSV 11749

In Fig. 4 we compare B-lightcurves of our  $0.561$ ,  $0.564$  and  $0.584M_{\odot}$  sequences with the photographic lightcurve reconstructed by Williams (2005). As can be seen, the theoretical lightcurves account for the brightening speed

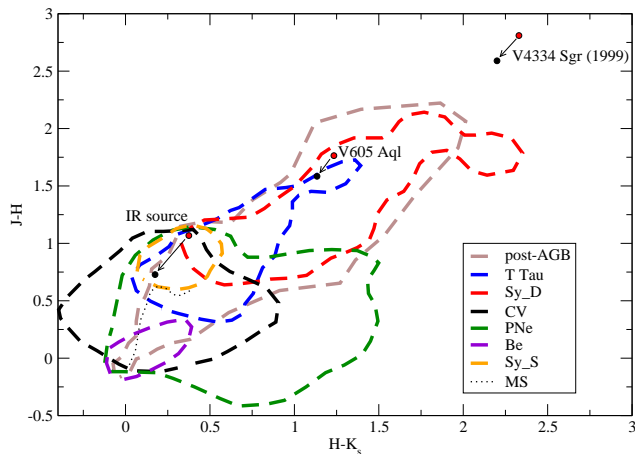


FIG. 5.— 2MASS color-color diagram for the source at coordinates of NSV 11749 compared with the 2MASS colors of known VLTP objects. Also shown are sketches of the location expected for different types of objects according to Viironen et al. (2009a,b). Red dots indicate observed colors and black dots dereddened colors.

observed in NSV 11749 of about  $\sim 0.5$  magnitudes per year. Also, our lightcurves predict that the star will stay at maximum brightness for a few years. More interesting NSV 11749 has shown three sudden extinctions between 1907 and 1910 before disappearing from Harvard plates in 1912. These extinctions occur when our sequence shows a temperature  $\log T_{\text{eff}} \lesssim 3.8$  and thus when real born again stars have shown us that RCrB-like extinction events are expected to occur. Thus, our sequences not only reproduce the eruption lightcurve but also agree with the interpretation of the three drops in brightness observed in NSV 11749 as being caused by RCrB-like events. Then, our models show that while NSV 11749 has increased its brightness by a factor about 2 to 4 slower than V4334 Sgr or V605 Aql, its lightcurve is well within the expected behavior for VLTP eruptions of different masses. Comparing the absolute magnitudes of the theoretical models with those observed in NSV 11749,  $B - M_B \sim 16^m$  for our  $0.564M_{\odot}$  sequence, we roughly estimate a distance of  $d \sim 3.2$  kpc and  $A_B \sim 4.2$ . Had we compared with our  $0.561M_{\odot}$  ( $0.584M_{\odot}$ ) sequence, for which  $B - M_B \sim 15.25^m$  ( $B - M_B \sim 16.3^m$ ), we would have estimated a distance of  $\sim 2.3$  kpc ( $\sim 3.6$  kpc) and  $A_B \sim 4$  ( $A_B \sim 4.3$ ). It must be noted that these distance estimates are very uncertain as they not only depend on the accuracy of born again models but also distances could be much larger if  $A_B$  is overestimated by Hakkila et al. (1997).

#### 4. POSSIBLE PRESENT COUNTERPART OF NSV 11749

Prompted by the strong resemblance of NSV 11749 with born again lightcurves (real and theoretical) we looked into 2MASS (Cutri et al. 2003) and IPHAS (González-Solares et al. 2008) catalogs for possible counterparts. If NSV 11749 experienced a born again event  $\sim 100$  yr ago we would expect it to be, by now, either enshrouded in a thick dust shell similar to post-AGB stars or reheating as a new central star of a planetary nebulae (as seen in V605 Aql). In order to constrain our search for present counterparts coordinates for NSV 11749 have been redetermined by the Digital Access to a

Sky Century at Harvard (DASCH, Grindlay et al. 2009) team from 6 plates from the Harvard College University plate archive. These plates were scanned and analyzed with the DASCH photometry pipeline, which yielded coordinates  $\alpha = 19^h07^m42.41^s$  and  $\delta = 00^{\circ}02'51.4''$  with a RMS error of  $\sigma \sim 1''$ . Their photometry was also consistent with that presented by Williams (2005).

Only one infrared source (from now on IRS) very near to the location of NSV 11749,  $\alpha = 19^h07^m42.4^s$  and  $\delta = 00^{\circ}02'51.0''$ , is within  $3\sigma$  from the derived coordinates. The IRS is included in both 2MASS and IPHAS catalogs with magnitudes  $J = 10.794$ ,  $H = 9.726$ ,  $K_s = 9.351$  (2MASS) and  $r' = 14.509$ ,  $i' = 13.053$ ,  $H_{\alpha} = 12.994$  (IPHAS). As shown in Fig. 5, 2MASS colors for the IRS are consistent with those of symbiotic stars, T-Tauri stars, cataclysmic variables, post-AGB stars and PNe. Also, dereddened colors (Rieke & Lebofsky 1985, assuming  $d = 3.2$  kpc) fall very close to main sequence stars. Fortunately, IPHAS colors for NSV 11749 fall above the cut defined by Viironen et al. (2009a) to isolate emission line objects (Zone 2, see Fig. 1 of Viironen et al. 2009a) and we can discard a main sequence star. Also, IPHAS colors fall in a region of the color-color diagram populated by symbiotic stars, T-Tauri stars and PNe but away from post-AGB stars (the IRS has higher  $H_{\alpha}$  brightness). Note, however, that despite the similar IPHAS and 2MASS colors, a FU Ori (i.e. T-Tauri) or symbiotic nova (i.e. symbiotic star) explanation for NSV 11749 is unlikely (see next section). In Fig. 5 we also compare the 2MASS colors of the IRS with those derived for V4334 Sgr and V605 Aql —dereddened assuming recommended distances of  $d = 2$  kpc and  $d = 3.5$  kpc respectively. As it is apparent, 2MASS colors for the three objects are very different. The IRS is bluer than dust enshrouded symbiotic stars (Sy\_D) and dust enshrouded VLTP objects. Thus, 2MASS colors suggest that the IRS is not strongly enshrouded by dust. Also the IRS is much brighter than the present state of V605 Aql, which is suspected to be completely hidden behind a thick dust torus (Clayton et al. 2006) but similar to the brightness of V4334 Sgr before the beginning of dust extinction events ( $J \sim 9.5...7$ , Tatarnikov et al. 2000).

Finally, an old PN would be expectable within the born again scenario, as all previous born again objects (FG Sge, V605 Aql and V4334 Sgr) show such PNe. Inspection of UKST and IPHAS images around NSV 11749 do not reveal any PN around the eruption. However, as the formation of a PN depends on the evolutionary speed of its central star, the absence of a PN could be just the consequence of a different mass of the erupting star (as already suggested by its lightcurve). Finally, note that, material ejected during the eruption (assuming 100 km/s as in V605 Aql, Clayton & De Marco 1997) would be smaller than  $1''$  and, thus, not resolved. If NSV 11749 was a VLTP, the progenitor star had to be different from those of V605 Aql and V4334 Sgr as the object does not seem to be now surrounded by a PN or enshrouded in a thick dust shell.

<sup>1</sup> These coordinates are remarkably close to those suggested by Williams (2005) which are several arcmins away from those recorded in the NSV catalog. This is because NSV coordinates correspond to Luyten's published discovery position, that was only estimated from grids traced over the plate (Williams private communication).

## 5. DISCUSSION AND FINAL REMARKS.

Based on its photometric lightcurve, Williams suggested two possible scenarios to explain NSV 11749, either a slow nova or a FU Ori type star. In particular a FU Ori event would be consistent with the 2MASS colors of the IRS that show it similar to T-Tauri stars. However as already mentioned by Williams (2005) these scenarios are unable to account both the brightness increase and dimming. While slow novae decline in timescales of the order of a year (Harman & O'Brien 2003) in qualitative agreement with NSV 11749, their rising is much faster increasing more than 5 magnitudes in a few days. The opposite happens with the FU Ori scenario. While typical FU Ori stars increase their brightness in a period of the order of a year their dimming is extremely slow, declining only a few magnitudes in decades (Hartmann & Kenyon 1996). Then both scenarios fail to match the observed behavior of NSV 11749 with both rising and dimming taking place in timescales of years.

A third alternative scenario suggested by the slow rising lightcurve is that of a symbiotic nova (also known as very slow novae, see Mikolajewska 2010 for a review). Symbiotic novae are thermonuclear novae that take place in symbiotic binary systems that would allow a natural link with the IRS identified in the previous section. The eruption period of these objects can last from month to years, thus naturally accounting for NSV 11749 observed eruption lightcurve. However the decline of these eruptions is extremely slow lasting for decades and even centuries (e.g. PU Vul). Thus, as in the case of the two previous scenarios, no simultaneous agreement with the eruption and declining timescales can be achieved.

Clearly, the born again scenario outperforms all other proposed explanations for NSV 11749. In fact, as discussed in Sect. 2, the qualitative agreement between the lightcurves of NSV 11749 and known VLTP objects is

very good. The most significant quantitative difference is that NSV 11749 eruption was a few times ( $\sim 5$  times) slower with the rising taking place in about 5 years. However, we have shown in previous sections that these differences are expectable from differences in the mass of the star and, even better, that NSV 11749 lightcurve can be quantitatively reproduced by VLTP models. In fact, differences in mass of the star could be related with the absence of a PN around the eruption.

With the aid of synthetic born again lightcurves we have presented strong arguments in favour of a VLTP explanation for NSV 11749. If this is so, NSV 11749 has some differences with both V4334 Sgr and V605 Aql (no PN, probably not enshrouded by dust). This finding will strongly increase our understanding of the late stages of stellar evolution. In particular it will boost our understanding of the formation of H-deficient stars and of the reactive-convective burning phases of stellar evolution.

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